Measurement of Neutrino Mass Hierarchy with Reactor Antineutrinos*

With the measurement of θ_{13}[1], one of the most pressing questions remaining about neutrinos is their mass hierarchy: whether the lightest mass state is a doublet (normal hierarchy) or a singlet (inverted hierarchy). Measurement of the hierarchy is accessible in reactor electron antineutrino disappearance experiments with very large liquid scintillator detectors located about 60 km (θ_{12} minimum) from powerful nuclear reactor complexes[2]. This approach is complementary to that from electron neutrino appearance in accelerator experiments. The two different mass hierarchies introduce phase shifts of opposite sign to the subdominant oscillations associated with the atmospheric mass splitting in the antineutrino energy spectrum. To make a significant measurement of the neutrino mass hierarchy in such an experiment one needs excellent energy resolution and well-calibrated detector energy response. With ~60 keV resolution at 4 MeV and nonlinearities measured to a fraction of 1% over the 2-8 MeV antineutrino energy range[3], a $\Delta\chi^2$=16[4] measurement can be made in five years with an exposure of 800 kT-GW_{th} per year. Such an experiment would also make precision measurements of θ_{12}, Δm^2_{21} and Δm^2_{32} and would potentially be sensitive to additional physics such as geoneutrinos, solar neutrinos, and atmospheric neutrinos. If we are lucky enough to witness a supernova within 10 kpc during the experiment's live time, we expect ~6000 events with very accurately measured energies.

A reactor neutrino experiment (presently called Daya Bay II) that would measure the mass hierarchy is being proposed in China. The proposed detector contains 20kT of liquid scintillator under a ~700 m rock overburden and is located 60km from two nuclear power plants totaling ~40 GW_{th} currently under construction. This experiment should record ~10^5 inverse beta decay ($\bar{\nu}_e + p \to e^+ + n$) events in a five year run. The current estimated cost of this experiment is a few hundred million dollars with an estimated 5 years for construction. Primary support for this experiment from Chinese funding agencies appears very promising and there are substantial opportunities for international collaboration. R&D and site investigations in China are underway. Data taking could begin around 2020.

There are many challenges to successfully mounting such an experiment. In addition to the very large detector volume and very good energy resolution, precision energy calibration is critical. Excellent energy resolution can be accomplished with >80% photocathode coverage, enhanced scintillation light yield and very long scintillator light attenuation lengths (>30 m). Calibration of such a large detector to the required precision is non-trivial. Deployment of calibration sources poses engineering challenges, and the energy scale requirements demand a comprehensive suite of calibration sources and detector response measurement at the sub-1% level, as well as detailed Monte Carlo simulations. These challenges require an intensive, targeted R&D program. US groups with extensive experience in solar, reactor and atmospheric neutrino experiments such as SNO, KamLAND, SuperK and Daya Bay are in an excellent position to undertake this R&D program for the experiment.

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